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SPACECRAFT PERFORMANCE ANALYSIS

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

SPACECRAFT PERFORMANCE ANALYSIS

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ABSTRACT

The performance lives of a random sample, and of one year design spacecraft, are examined in an effort to provide information concerning the useful life of a spacecraft system exclusive of experiment performance.

CONTENTS

SPACECRAFT PERFORMANCE ANALYSIS

INTRODUCTION

In response to a request to the Program Support Division, the Cost Experience Group of the Business Management Office has investigated performance of spacecraft developed under Goddard management in order to gain insight into the useful life of a spacecraft system exclusive of experiments. The information is intended to aid in amortizating spacecraft costs over an expected useful life, and support the case for demonstrating the potential of long-lived unmanned satellites in the 70's.

The initial analysis attempted to show the progressive growth in performance of satellites in orbit which could be projected. This approach was inconclusive. The approach then turned to utilizing a comparison of the mean design life and mean performance months by year of launch, the separation of follow-on designs as a discrete sample, and the development of a meantime to failure for the spacecraft samples using a reliability calculator based on total performance hours and number of failures.

The initial findings were based on a random sample of twenty-five spacecraft, of which twenty-four provided useful data points. (See Appendix A.) The random sample indicated a 95% confidence for a meantime to failure of 36 months for a 12 month design life follow on satellite.

Due to the limited number of 12 month designs in the original sample, an enlarged sample was sought. An attempt was made to identify the design life of all Goddard managed Spacecraft. Thirty (30) one year design spacecraft were identified and useful performance life was determined from documents and appropriate project personnel.

The results of this analysis support the random sample analysis. The total sample, thirty (30) spacecraft, indicated a Mean Time to Failure (MTF) of thirty-four (34) months at a 95% confidence level and a MTF of thirty-eight (38) months at a 95% confidence level for the follow on design sample consisting of eighteen (18) spacecraft. A follow on spacecraft is considered to be a result of a continuing program using spacecraft designs proven in earlier spacecraft operation.

An attempt to designate a mode of failure was complicated by the "graceful" degrading effect.* The suspected modes of failure will not be presented in this

*Flatow, Fred S., Reliability Assessments for Spacecraft - What Can They Accomplish; GSFC X-301-68-100, March 1968.

document due to their controversial nature and lack of significant contribution to the findings which are directed to "when" a failure, as defined by the criteria for measurement of performance, has occurred rather than the "how" of failure.

CRITERIA FOR MEASUREMENT OF PERFORMANCE

The design life for purposes of this analysis is the design goal or longest period of operation expected at the time of launch as documented in the Project Development Plan (PDP), or other documentation of mission goals and success criteria. When this type of information was not available the existence of a 12 month design goal was confirmed by individuals familiar with the mission, e.g., project manager or other responsible individual involved in the mission.

The analysis is concerned with the operating life of the spacecraft independent of experiment life. To perform this artificial isolation of spacecraft subsystems and experiments those subsystems of the "bus" which provide the environment necessary to support a sensor were selected as the indicators of satisfactory performance. Only spacecraft which obtained orbit were considered in the analysis of performance.

The failure of the control, power, communications or data handling subsystems to provide the designed support for satisfactory operation of a sensor, regardless of the ability of the sensor to function, is considered to be the failure point of the spacecraft in this analysis.

The spacecraft is performing satisfactorily if it is maintaining a satisfactory attitude, temperature, providing power and capable of receiving and transmitting data. A tape recorder failure did not disqualify a spacecraft if useful amounts of real time data can be collected. Spacecraft operation on solar cells at favorable sun angles following loss of battery storage is satisfactory performance when useful amounts of data can be collected.

In the one year design life study, a condition considered a failure for analysis purposes which does not stop transmission of useful data is described as an anomalous operation. The graphical presentations identify anomalous actions by a square (□). Only the performance hours prior to commencement of anomalous operation are used in the MTF analysis on the decay graphs. The OGO series when operating in its spin mode is considered anomalous. The IMP-B operating hours are considered anomalous due to its improper orbit.

The results of the performance life decay graphs and the 95% confidence level of the Mean Time to Failure (MTF) analysis are shown in tabular form in Table I-1. The related graphs and sample descriptions are found in Graphs I-4 through I-7, and Tables I-3 and I-4 respectively.

PART I

SPACECRAFT PERFORMANCE ANALYSIS OF A RANDOM SAMPLE

PART I

TABLES AND GRAPHS

RESULTS OF ANALYSIS OF THE RANDOM SAMPLE

The analysis presents sample points by comparing performance life to design life, and by examining the follow-on spacecraft as a discrete sample. The data points are developed from Table I-2 (Data Sheet Performing Analysis). The results show that the follow-on spacecraft performance exceeded the first launch spacecraft performance significantly (graph one). The mean performance months to design months ratio has remained between 2.0 and 3.0 while mean design life has increased from 3 months to 9.0 months (graphs two and three).

MEAN TIME TO FAILURE (MTF) ANALYSIS OF THE RANDOM SAMPLE

In order to project the existing data into a measure of Mean Time to Failure a reliability calculator was used.* Given the performance hours and number of failures the calculator fixes a failure rate per cent per 1,000 hours, and a mean time to failure. Confidence levels range from 99% to 50/50 or best estimate. In this analysis the spacecraft is assumed to be the unit under test. Spacecraft which are operating or were turned off while operational are not considered to have failed. Performance hours are measured from day of launch to day of failure or shut down, or to the end of the study period.

The confidence level used in application of this data is a matter of individual choice. For the amortization of cost and consideration given in performance incentives a best guess or 50/50 confidence may be a suitable choice. In the estimation of useful performance in support of a sensor a higher confidence, with resultant reduction in MTF would seem more realistic.

*The reliability calculator used was a circular slide rule as used in test condition environments. The failure rate and Mean Time to Failure (MTF) are computed at the spacecraft level from the total performance hours and the number of spacecraft failures. The validity of the slide rule estimate is tested by establishing approximate confidence intervals in Appendix B.

Table I-1

Summary of Results

Sample and Number of Spacecraft (SC)	Total Performance in Months Σ Performing Months (P)	Total Design Months Σ Design Life (DL)	Mean Performance Months ($\bar{P}$)	Mean Design Life ($\overline{DL}$)	Performance to Design Month Ratio ($\bar{P}/\overline{DL}$)	MTF in Months 95% Confidence	Number of Spacecraft Operating 1-22-69
Random Sample 24 S/C	452.5	225.6	18.8	9.4	2.0:1.0	24	7
Random Sample Follow-on 16 S/C	405.3	129.0	25.3	8.1	3.1:1.0	38	7
12 Mo Design in Random Sample 12 S/C	243.6	144.0	20.3	12.0	1.7:1.0	16.5	4
12 Mo Design Follow-on in Random Sample 7 S/C	215.3	84.0	30.8	12.0	2.6:1.0	27	4

Table I-2

Data Sheet Random Sample Performance Analysis

Flight	Launch Date	Failure Date	Performance Time			Design Life Months	Performance Notes
			Mos	Days	Hrs		
TIROS I	4-01-60	6-16-60	2.5	77	1848	3	1
TIROS III	7-12-61	8-07-62	13	394	9456	3	3
TIROS IV	2-08-62	9- -62	7	203	4872	3	3
OSO I	3-07-62	8-06-63	17	517	12408	6	1-3
SYNCOM I	2-14-63	2-14-63	0	0	0	12	1
TIROS VII	6-19-63	12-06-65	29	903	21672	3	3
SYNCOM II	7-62-63	----	66	2002	48048	12	2
IMP-A	11-27-63	5-06-64	6	164	3936	12	1
IE-A	8-25-64	12-29-64	16	490	11760	12	1
NIMBUS I	8-28-64	9-23-64	1	27	648	6	1
BE-B	10-10-64	----	51	1561	37464	12	2
BE-C	4-29-65	4-05-68	36	1071	25704	12	
IMP-C	5-29-64	5-12-67	24	714	17136	12	
OGO II	10-14-65	10-24-65	.3	10	240	12	
ESSA II (OT-2)	2-08-66	----	35	1078	25872	6	1-2
OAO I	4-08-66	4-09-66	--	1.5	36	12	
NIMBUS II	5-15-66	1-16-69	32	973	23352	6	
ESSA III	10-02-66	10- -68	24	728	17472	6	
ESSA IV	1-26-67	5- -68	16	462	11088	6	3
ESSA V	4-20-67	----	21	644	15456	6	2

1 - Identifies a first in series spacecraft.
2 - Spacecraft remaining operational as of January 22, 1969.
3 - Spacecraft shut down or no longer monitored as of failure date.

Table I-2 (Continued)

Flight	Launch Date	Failure Date	Performance Time			Design Life Months	Performance Notes
			Mos	Days	Hrs		
IMP-F	5-24-67	----	20	609	14616	12	2
OGO IV	7-28-67	----	18	546	13104	12	2
OSO IV	10-18-67	----	13	462	11088	6	2
TTS-1	12-13-67	5- -68	5	140	3360	12	1

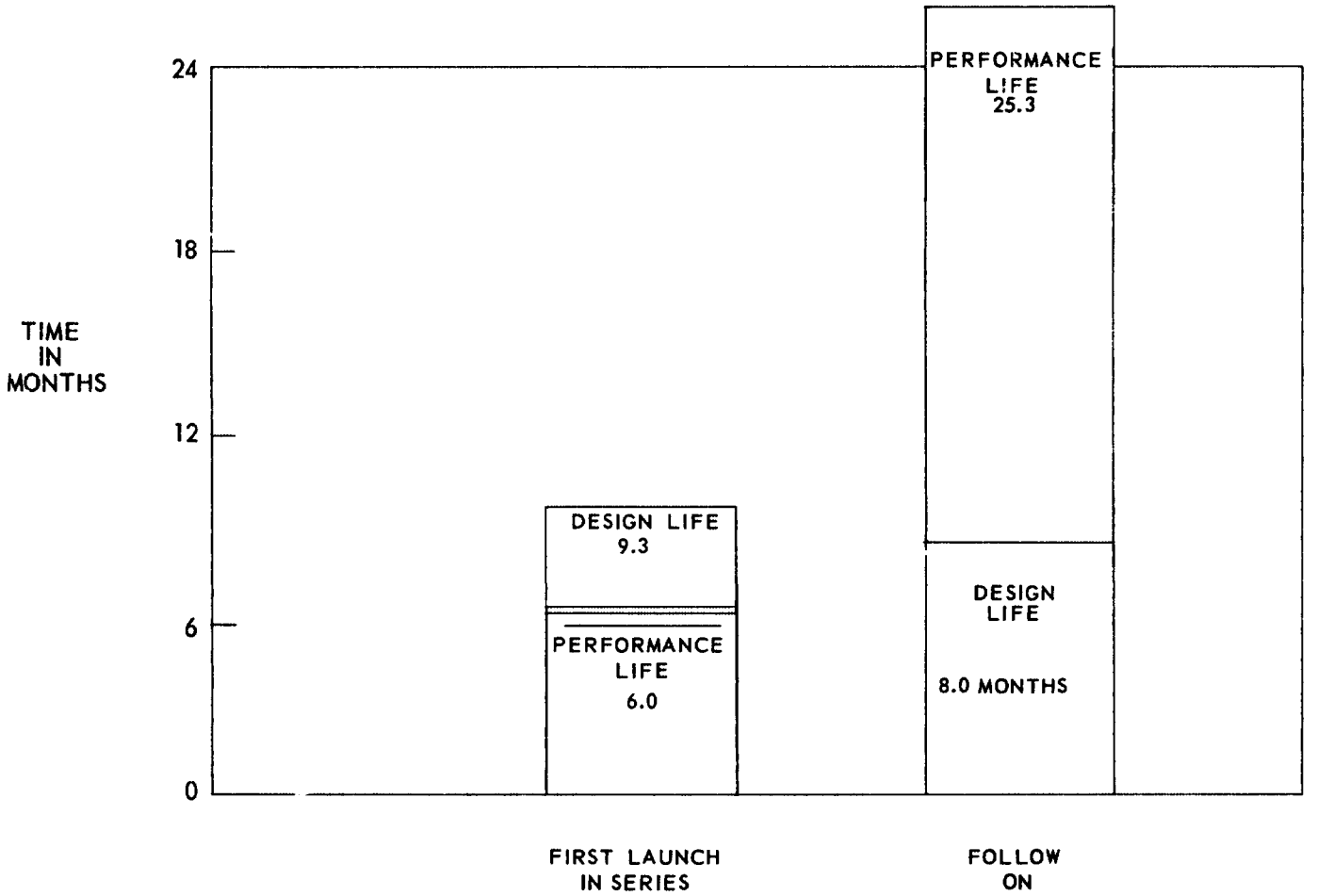
1 - Identifies a first in series spacecraft.
2 - Spacecraft remaining operational as of January 22, 1969.
3 - Spacecraft shut down or no longer monitored as of failure date.

Graph I-1

Mean Satellite Design Life and Performance Life-First Launch Versus Follow-on Satellites

Graph 1 compares the mean performance life to the mean design life of the first S/C in any launch series to the performance of life of the remaining S/C.

Satellites First in Series	Follow-on Satellites
TIROS I	TIROS III
OSO I	TIROS IV
SYNCOM I	TIROS VII
IMP-A	SYNCOM II
IE-A	BE-B
NIMBUS I	BE-C
OAO I	IMP-C
TTS I	OGO II
	ESSA II (OT-2)
	NIMBUS II
	ESSA III
	ESSA IV
	ESSA V
	IMP-F
	OGO IV
	OSO IV



Graph 1-1. Mean Satellite Design Life and Performance Life First Launch vs Follow On Satellite

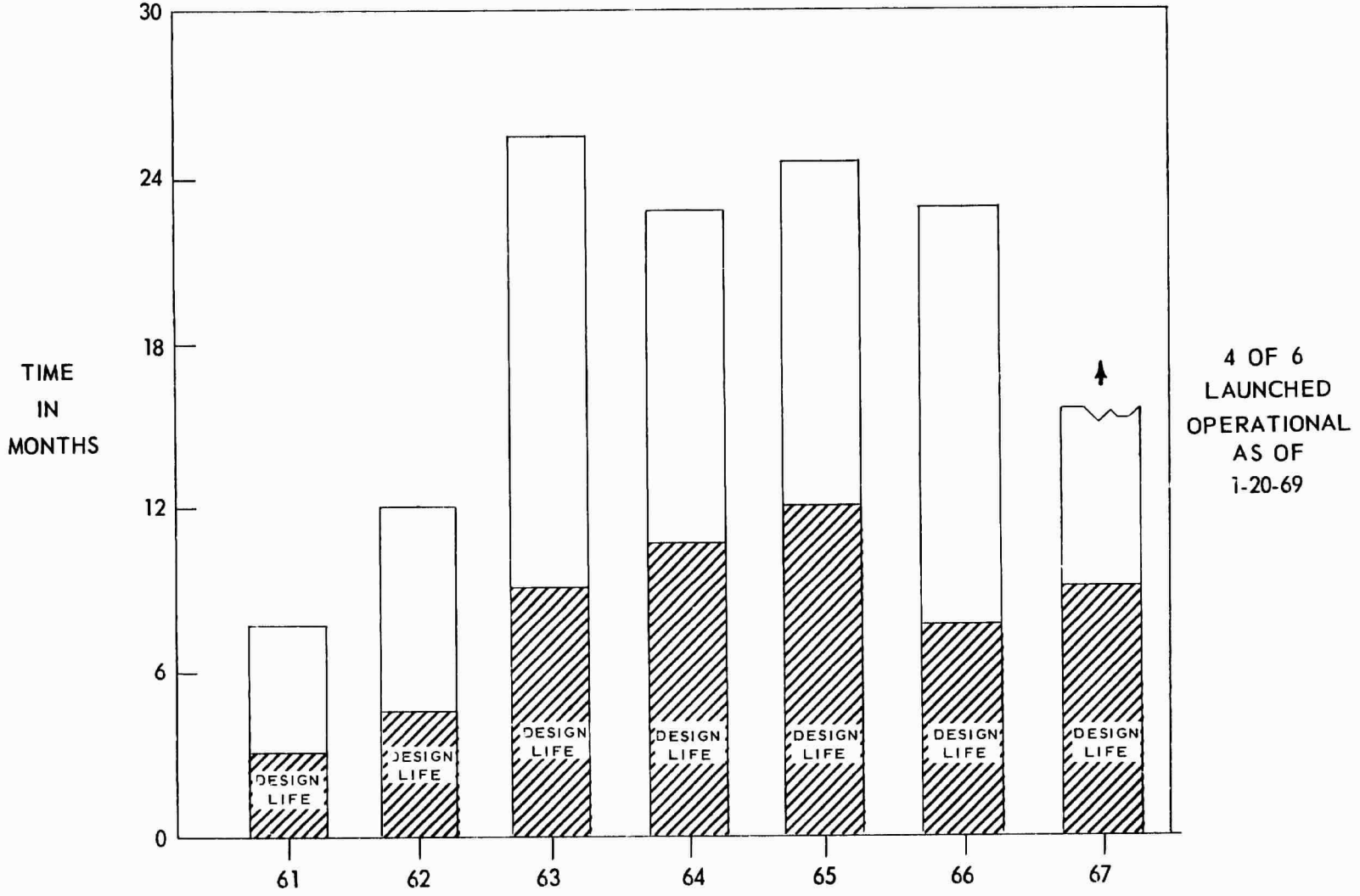
Graph I-2

Satellites Lifetime in Orbit

The mean design life for satellites launched in 1961 through 1967 is compared to the mean performance life by year. Operational satellites remain as follows:

1 each from Cy 63, 64, 66

4 from CY 67



Graph I-2. Satellites Mean Lifetime in Orbit by Year of Launch

Graph I-3

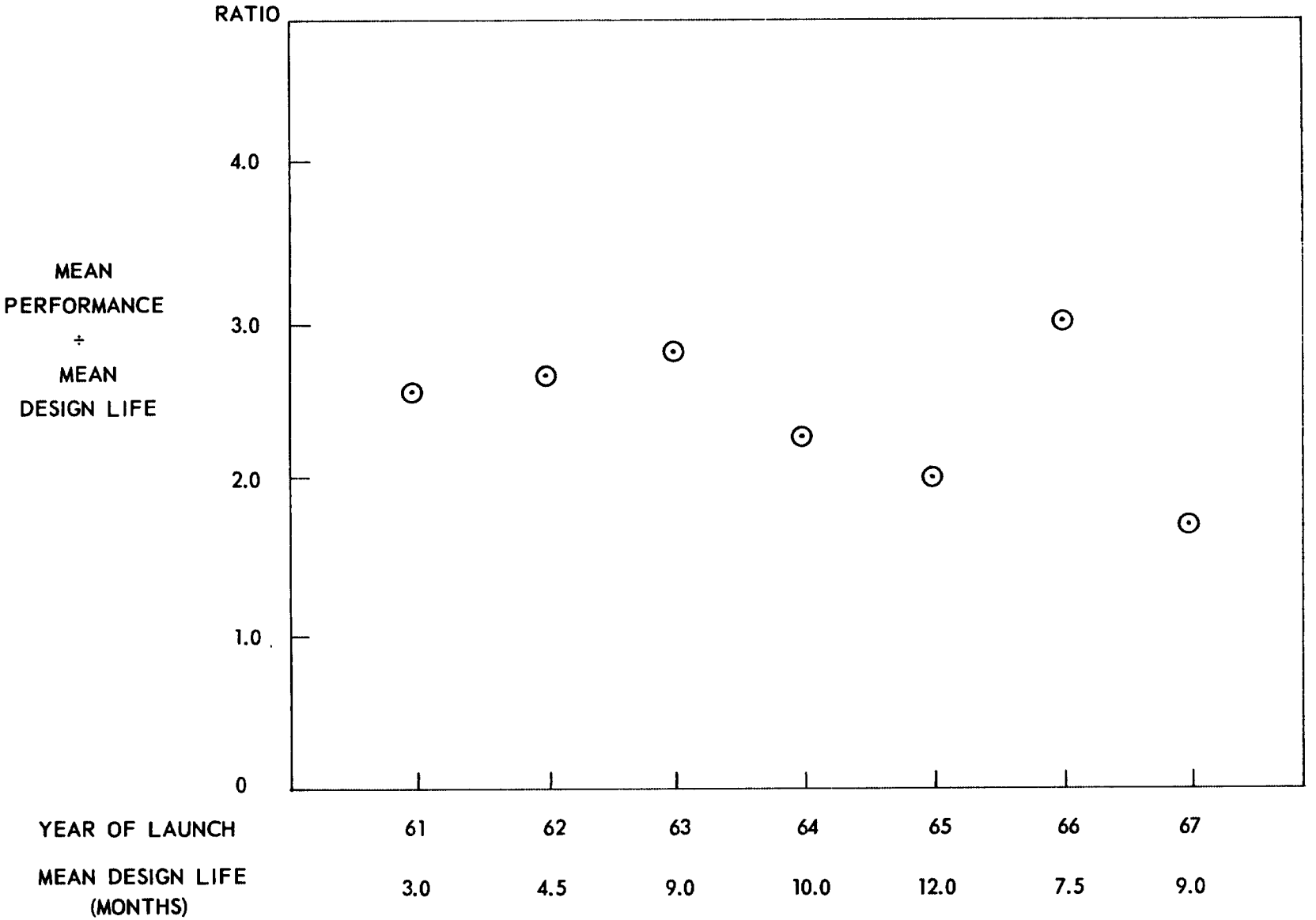
Mean Satellite Performance Months ÷
Mean Design Life by Year of Launch

Graph 3 is a plot of the mean performance design life ratio for sample satellites by year of launch.

Four of the six satellites in the CY 67 launch group are still operational. One S/C each in CY 63, 64, and 66 is operational.

CY 65 performance design life ratio was lowered due to the failure of the OGO II control system ten days after launch. While OGO II is still operational in its backup spin mode, it is considered a failure in the sample due to the existence of experiments requiring a stable platform in its payload.

CY 64 performance design life ratio is lowered by NIMBUS I.

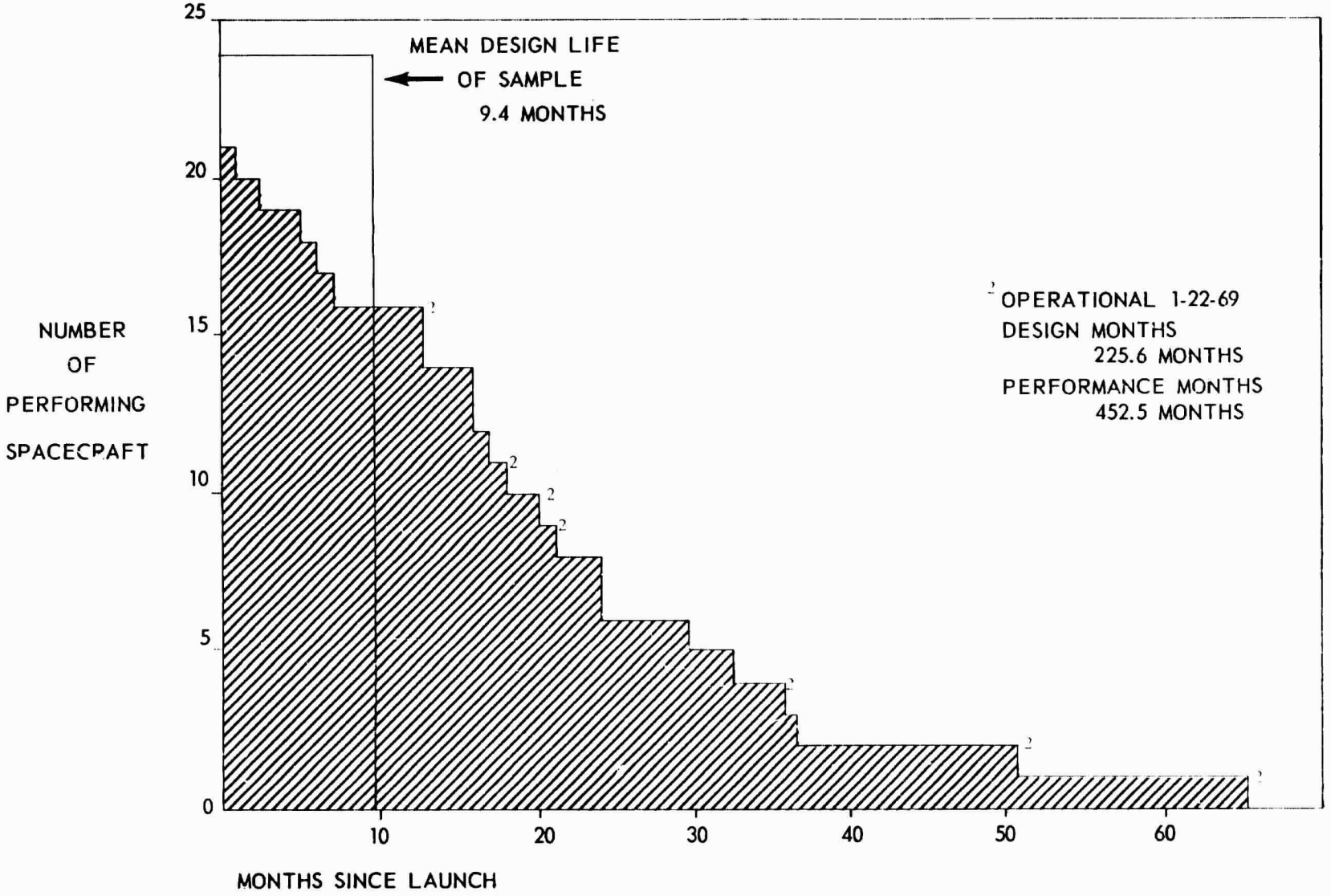


Graph I-3. Mean Satellite Performance Mean Design Life

Graph I-4

Performance Life Decay Random Sample

This graph compares the sample mean design life, 9.4 months, to the months performed by spacecraft in the sample. The area to the left of the design life line is 225.6 months (9.4 × 24 = 225.6). The area under the performance line is 452.5 months. Performance to design life ratio is 2.0. It should be noted that at the end of the sample period, January 22, 1969 there were seven operational spacecraft.

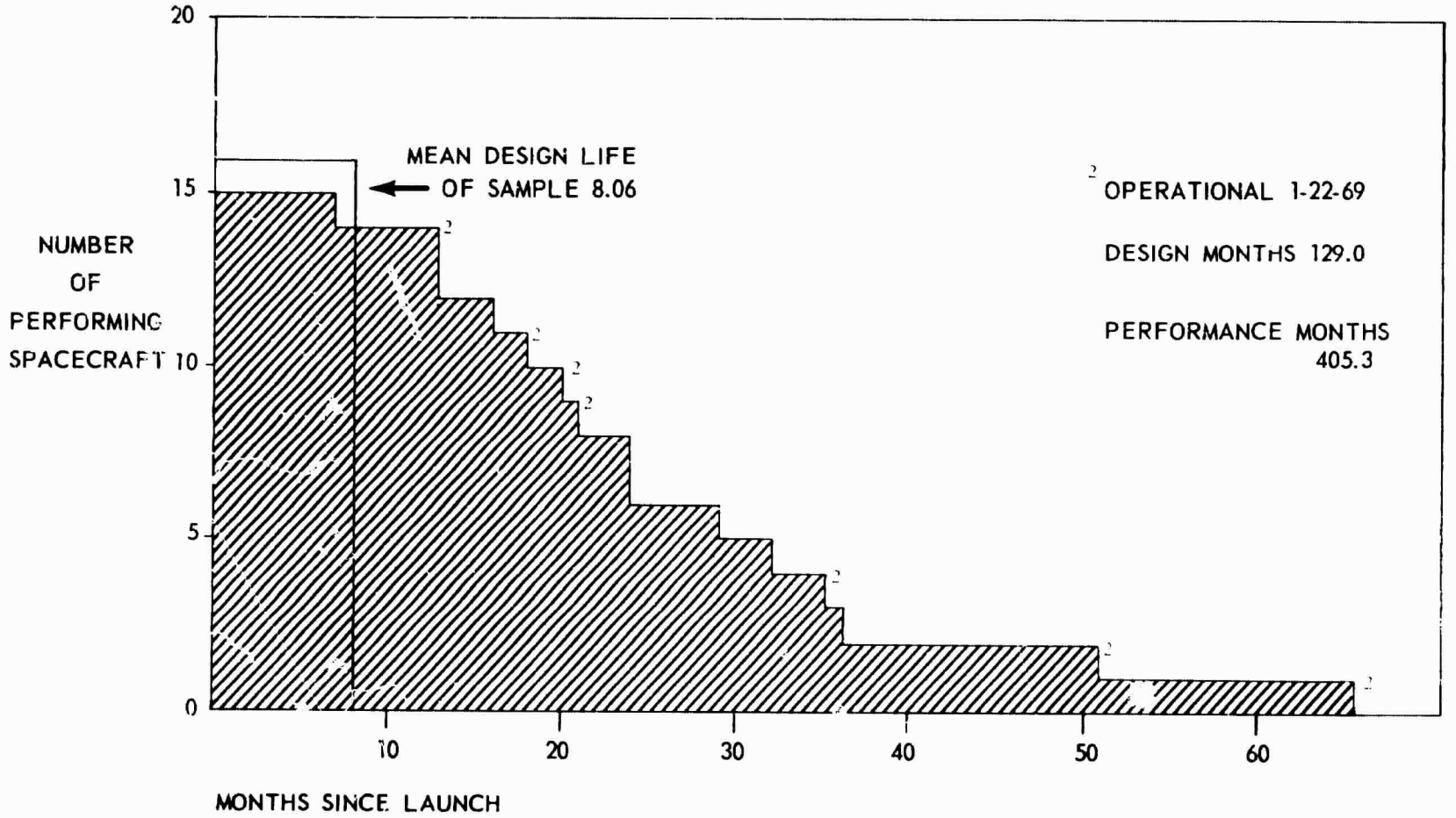


Graph I-4. Performance Life Decay Random Sample

Graph I-5

Performance Life Decay of Follow-on Missions

This sample represents the performance in months from date of launch for the sixteen follow-on spacecraft. At the end of the sample period, January 22, 1969, seven spacecraft remained operational. The performance months design months ratio is 3.1:1.0 as of January 22, 1969.



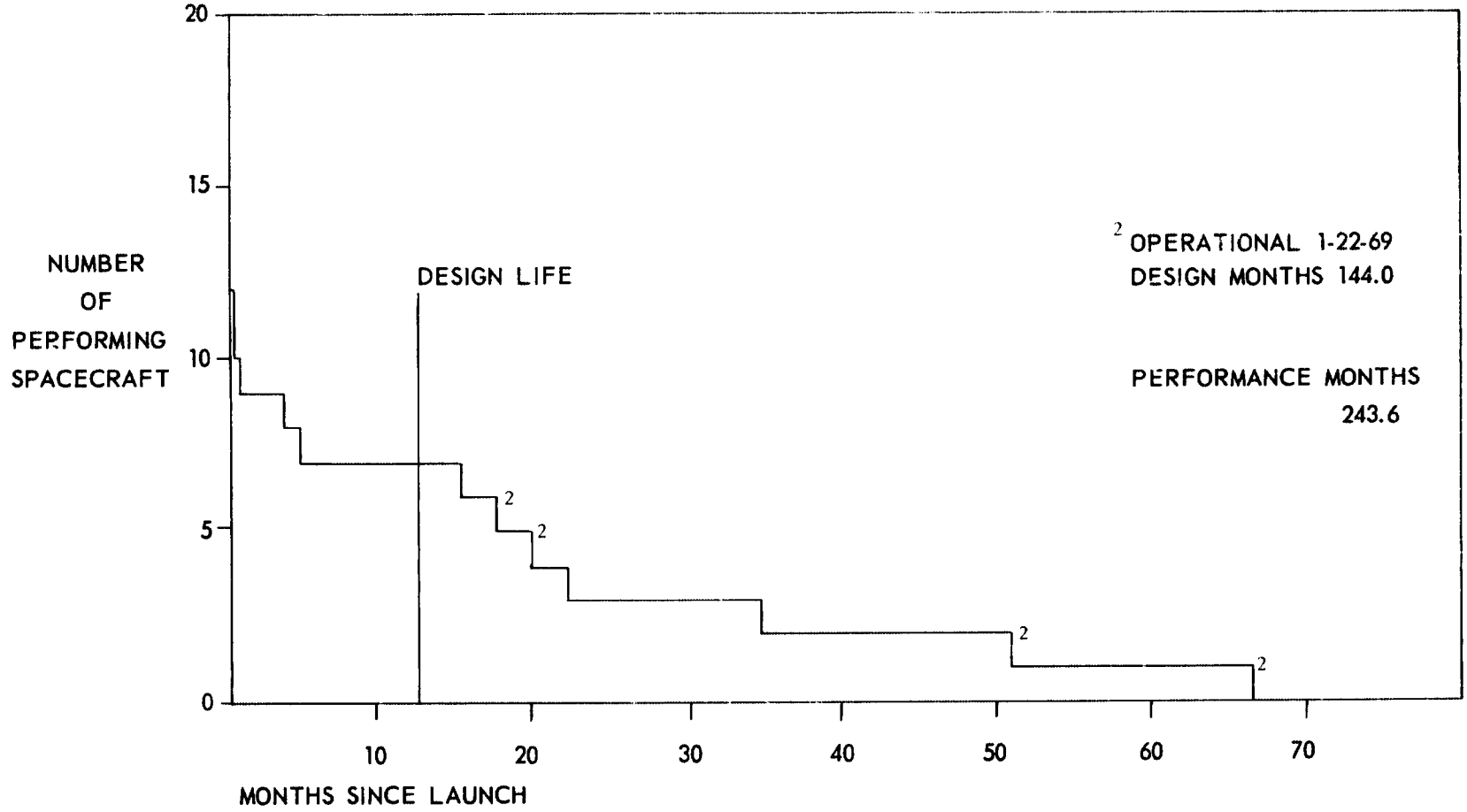
Graph I-5. Performance Life Decay Follow On Missions

Graphs I-6 and I-7

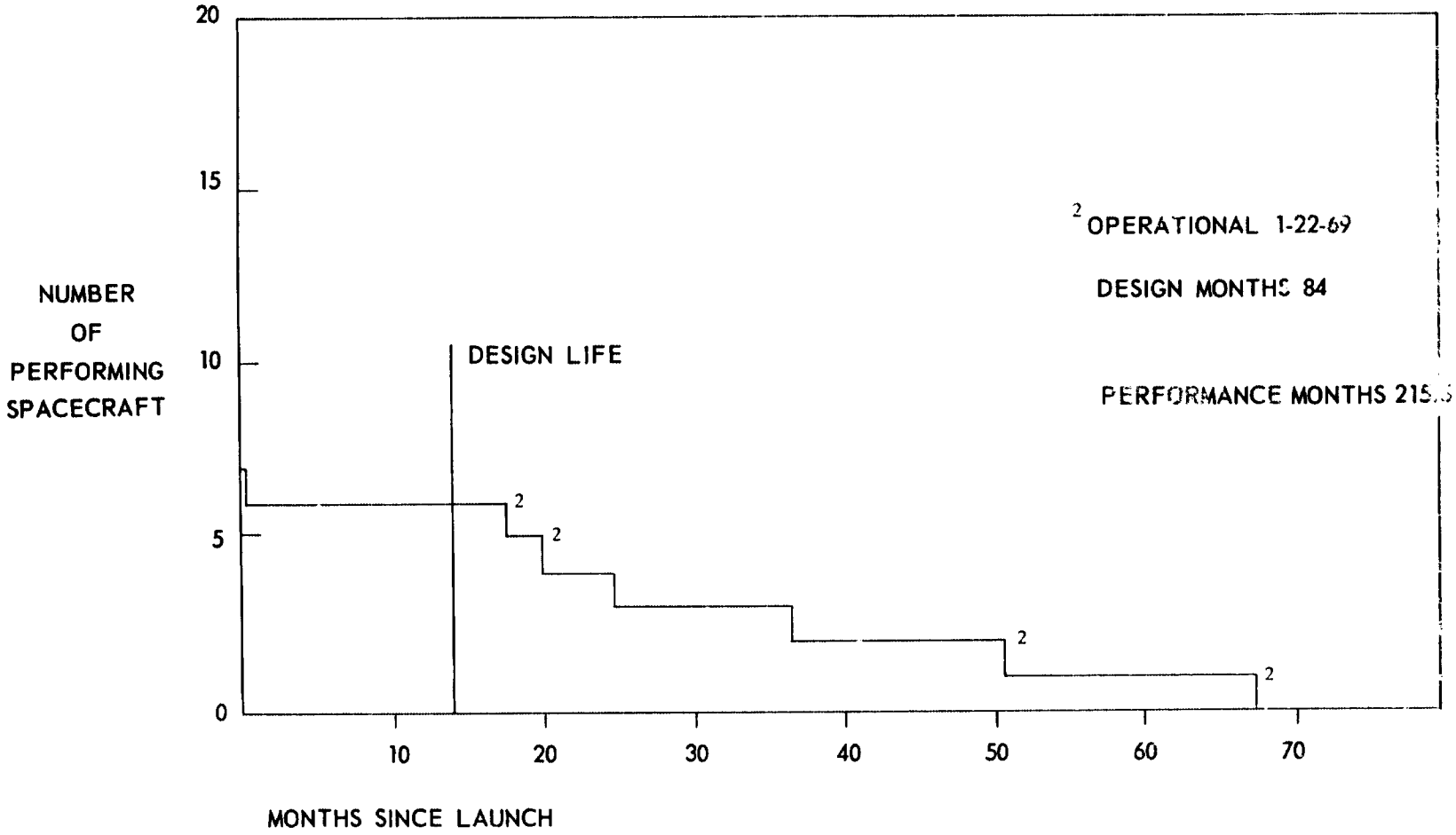
Performance Life Decay of One Year Design Life and One Year Design Follow-on Spacecraft

The random sample contains twelve one year design satellites of which seven are follow-on spacecraft. The performance month design month ratio for the one year design sample is 1.7:1.0. The follow-on performance month design month ratio for the follow-on spacecraft is 2.6:1.0.

The size of the sample was considered marginal for use in the analysis, therefore, a new sample of all identifiable one year designs is examined in Part II.



Graph I-6. Performance Life Decay One Year Design



Graph I-7. Performance Life Decay One Year Design Follow On

Table I-3

Mean Time to Failure Analysis

Total Performance Hours - 330,636	
Number in Sample - 24	
Number of Failures - 12	Other S/C in Sample - 12
TIROS I#1	TIROS III
SYNCOM I#1	TIROS IV
IMP-A#1	OSO I#1
IE-A#1	TIROS VII
NIMBUS I#1	SYNCOM II*2
BE-C	BE-B*2
IMP-C	ESSA II*2
OGO II	ESSA IV
OAO I#1	ESSA V*2
NIMBUS II	IMP-F*2
ESSA III	OGO IV*2
TTS-1#1	OSO IV*2

Confidence Level	MTF Hours	Months	Failure Rate % Per 1,000 Hrs.
99	14,700	20.4	6.8%
95	17,500	24.3	5.7%
90	18,900	26.3	5.3%
60	25,000	34.7	4.0%
50/50	26,900	37.3	3.7%

1. # First spacecraft in series.
2. * Operational spacecraft at end of sample period January 22, 1969.

Table I-4

Mean Time to Failure Analysis

Follow-on missions only	
Performance hours - 296,640	
Number of Failures - 5	Other S/C in Sample - 11
BE-C IMP-C OGO II NIMBUS II ESSA III	TIROS III TIROS IV TIROS VII SYNCOM II*[2] BE-B*[2] ESSA II*[2] ESSA IV ESSA V*[2] IMP-F*[2] OGO IV*[2] OSO IV*[2]

Confidence Level	MTF Hours	Months	Failure Rate % Per 1,000 Hrs.
99	22,900	31.8	4.4%
95	27,900	38.8	3.5%
90	32,000	44.4	3.1%
60	47,000	65.3	2.1%
50/50	51,000	70.8	1.9%

2. * Operational spacecraft at end of sample period January 22, 1969.

PART II

SPACECRAFT PERFORMANCE ANALYSIS
OF
ONE YEAR DESIGN SPACECRAFT

PART II

TABLES AND GRAPHS

ONE YEAR DESIGN LIFE SAMPLE

The one year design sample consists of thirty (30) one year design spacecraft. The sample consists of all Goddard Managed one year design life spacecraft for which design life and performance life could be fixed with reasonable accuracy.

The performance time is measured to a failure. A failure is the result of the control, power, communications, or data handling subsystems inability to provide the designed support for satisfactory operation of a sensor, irregardless of the ability of the sensor to function.

Total performance hours are noted in Table II-2. The performance hours including anomolous hours are shown separately for information only. The anomalous operation hours were not used in the MTF analysis or reflected in the graphical analysis.

The anomalous performance identified in Table II-2 and on the graphical analysis identifies a situation in which data collection from the spacecraft continued but performance was not adequate for the analysis. The OGO anomaly is the collection of data in the "backup" or spin-mode which does not provide designed support for satisfactory operation of all sensors. The IMP-A collected small amounts of useful data from May 30, 1964 to May 10, 1965 when at favorable sun angles. The IMP-B gathered useful data from October 4, 1964 to July 18, 1965 but the mission was classified as a failure due to improper orbit as a result of launch vehicle malfunction.

ANALYSIS OF ONE YEAR DESIGN SAMPLE

In the analysis of one year design, a conservative bias has been effected by the Criteria for Measurement of Performance. The exclusion of performance hours of the OGO in the spin mode, the exclusion of data from IMP-A following battery failure, and IMP-B in total due to improper orbit result in a reduction of 127 performance months in the analysis of performance of 12 month design spacecraft.

The mean performance in months has exceeded the design life consistently since 1962. The percentage of launched spacecraft remaining operational is 45% for all years after 1964 with no less than 40% remaining operational in each year since 1964.

The performance life decay graphs show a tendency for the spacecraft failure rate to decrease after an initial period of about six months from launch.

The initial or infant mortality in the first month accounted for 20% of the observed failures or anomalous occurrences in the sample. An additional 27% of the observed failures and anomalies occur in the next five months. A total of 47% of all observed failures or anomalies occur in the first six months following launch. During the remaining six months of the design life only 6.6% of the failures or anomalous occurrences were observed. The high initial mortality is not exhibited by the follow-on sample.

The results of the performance life decay graphs and the 95% confidence level of the Mean Time to Failure (MTF) analysis are shown in Table II-1. The related graphs and sample descriptions are found in Graphs II-3 and II-4 and Tables II-3 and II-4 respectively.

Table II-1

Summary of Results

Sample and Number of Spacecraft (SC)	Total Performance in Months Σ Performing Months ($\hat{P}$)	Total Design Months 30 × 12 (DL)	Mean Performance Months (1/2) ($\bar{P}$)	Mean Design Life ($\overline{DL}$)	Performance to Design Month Ratio ($\bar{P}/\overline{DL}$)	MTF in Months at 95% Confidence	Number of Spacecraft Operations 3-11-69
One Year Design 30 S/C	756	360	25.2	12	2.1:1.0	34	13
Follow-on Mission 18 S/C	517	216	28.7	12	2.4:1.0	39	10

Table II-2

Data Sheet for Twelve Month Design Sample

Spacecraft	Launch Date	Failure Date	Performance		Performance Notes
			Month	Hours	
Explorer VII	10-13-59	8-24-61	22	16344	1
Explorer XII	8-15-61	12-06-61	4	2736	1
Ariel I	4-26-62	11-09-64	31	22320	1, 3
Alouette I	9-28-62	----	77	56640	1, 2
Relay I	12-13-62	8- -65	32	23256	1
Syncom II	7-26-63	----	67	46992	2
(IMP-A) Explorer XVIII	11-26-63	5-30-64	6	4536	4
Relay II	1-21-64	----	62	42576	2
Ariel II	3-27-64	3- -66	24	17520	3
Syncom III	8-19-64	----	54	40080	2
(IE-A) Explorer XX	8-25-64	12-29-65	16	11760	1
OGO I	9-04-64	9-04-64	0	5	1, 4
(BE-B) Explorer XXII	10-09-64	----	52	38784	2
(S-3C) Explorer XXVI	12-21-64	5-26-67	29	21216	
(BE-C) Explorer XXVII	4-29-65	4-05-68	35	25944	
(IMP-C) Explorer XXVIII	5-29-65	5-12-67	24	17136	
OGO II	10-14-65	10-23-65	0	240	4
Alouette II	11-29-65	----	39	28800	2
(DMEA) Explorer XXXI	11-29-65	----	39	28800	2
OAO I	4-08-66	4-09-66	0	36	1
(AE-B) Explorer XXXII	5-25-66	3-22-67	10	7104	
OGO III	6-07-66	8-23-66	3	2040	4
AIMP-D	7-01-66	----	31	23736	2
ATS-1	12-06-66	----	27	19872	1, 2, 5

Table II-2 (Continued)

Spacecraft	Launch Date	Failure Date	Performance		Performance Notes
			Month	Hours	
(IMP-F) Explorer XXXIV	5-24-67	----	21	15816	2
(AIMP-E) Explorer XXXV	7-19-67	----	19	14520	2
OGO IV	7-28-67	1-19-69	19	13008	3, 4
ATS III	11-05-67	----	16	11856	2
TTS I	12-13-67	5- -68	5	3360	1
OGO V	3-04-68	----	12	8952	2

Performance Notes:

1. First spacecraft in series.
2. Spacecraft remains operational as of March 11, 1969.
3. Spacecraft shut down or no longer tracked as of failure date shown.
4. Spacecraft exhibited anomalous performance after failure date shown. Total measurable performance for anomalous spacecraft is as follows:

Spacecraft	Launch Date	Total Measured Performance	Performance	
			Months	Hours
(IMP-A) Explorer XVIII	11-26-63	5-10-65	18	12792
OGO I	9-04-64	----	52	39624
IMP B	10-04-64	7-18-65	9	6960
OGO II	10-14-65	11-01-67	25	17976
OGO III	6-07-66	----	32	24240
OGO IV	7-28-67	----	19	13992

5. ATS series design life exceeds 12 months but has been used as 12 months for purpose of this analysis.

Graph II-1

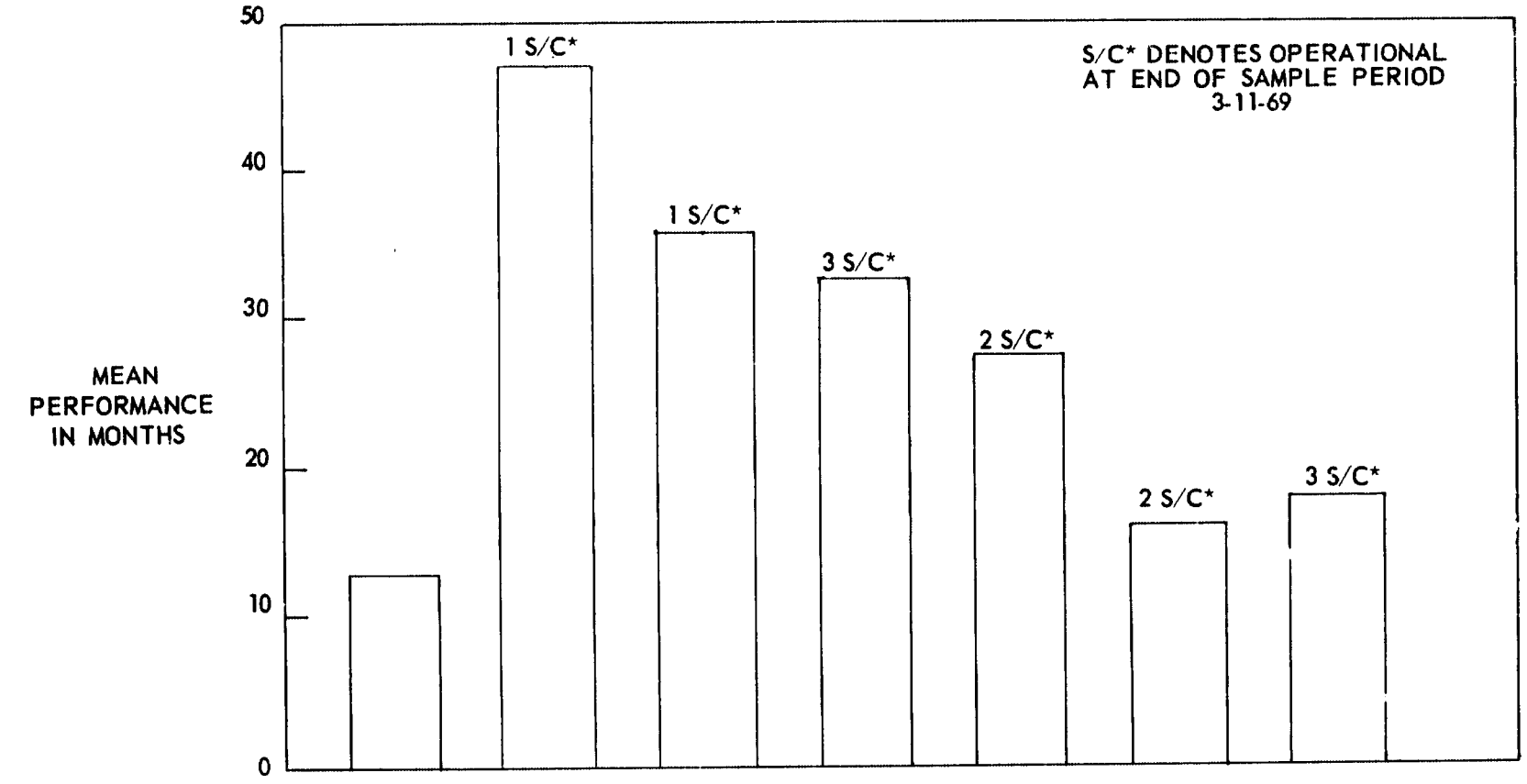
Twelve Month Design Life

Mean Performance in Months
vs.
Year of Launch

The OGO anomalous hours are not shown in 1964, 1965, and 1966. The 1966 performance months are also affected by the OAO I failure at launch.

The year of launch mean performance has exceeded the design life of 12 months in all samples. The 1959-1961 sample of two spacecraft is not considered to be significant due to the lack of complete documentation on design life criterion.

As a result of the MTF analysis, the spacecraft remaining operational in the 1966 and 1967 samples have a 99% confidence of reaching a 29 month performance level.



YEAR OF LAUNCH	59 to 61	62	63	64	65	66	67
TOTAL Performance Months	26	140	73	237	137	71	80
NUMBER LAUNCHED	2	3	2	7	5	5	5

Graph II-1. Mean Performance in Months vs Year of Launch

Graph II-2

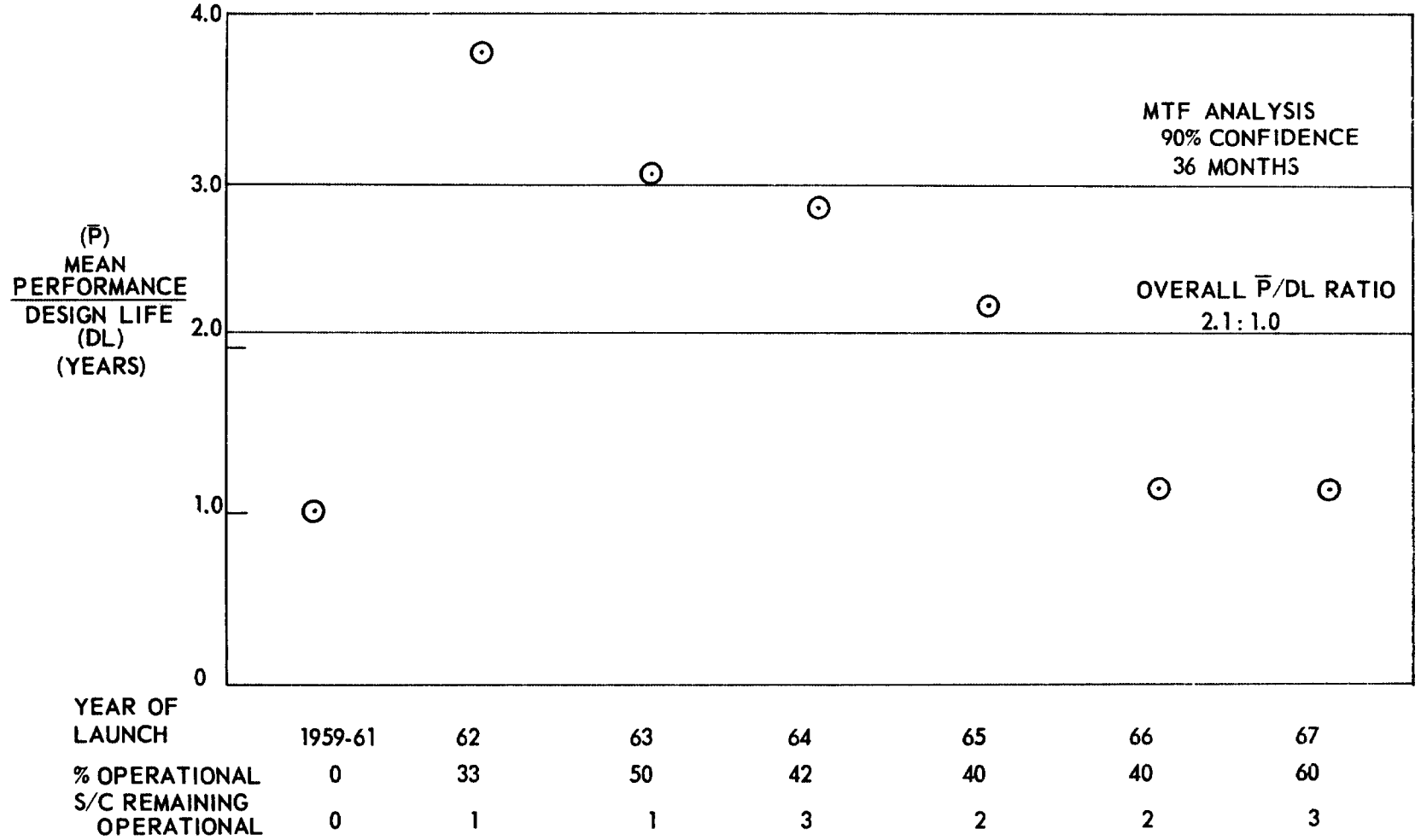
Twelve Month Design Life

Mean Performance Design
Life Ratio by Year

The remarks concerning anomalous hours from Graph II-1 are also true in this presentation.

The overall ratio of 2.1:1.0 is developed from Graph II-3. The follow-on ratio for all years which is not shown is 2.4:1.0 is developed from Graph II-4.

The results of the MTF analysis indicate a 90% confidence level in the launch year samples 1965, 1966 and 1967 mean performance design life ratio ($\bar{P}$/DC) reaching the 3.0 level.



Graph II-2. Mean Performance Design Life Ratio by Year

Graph II-3

Twelve Month Design Life

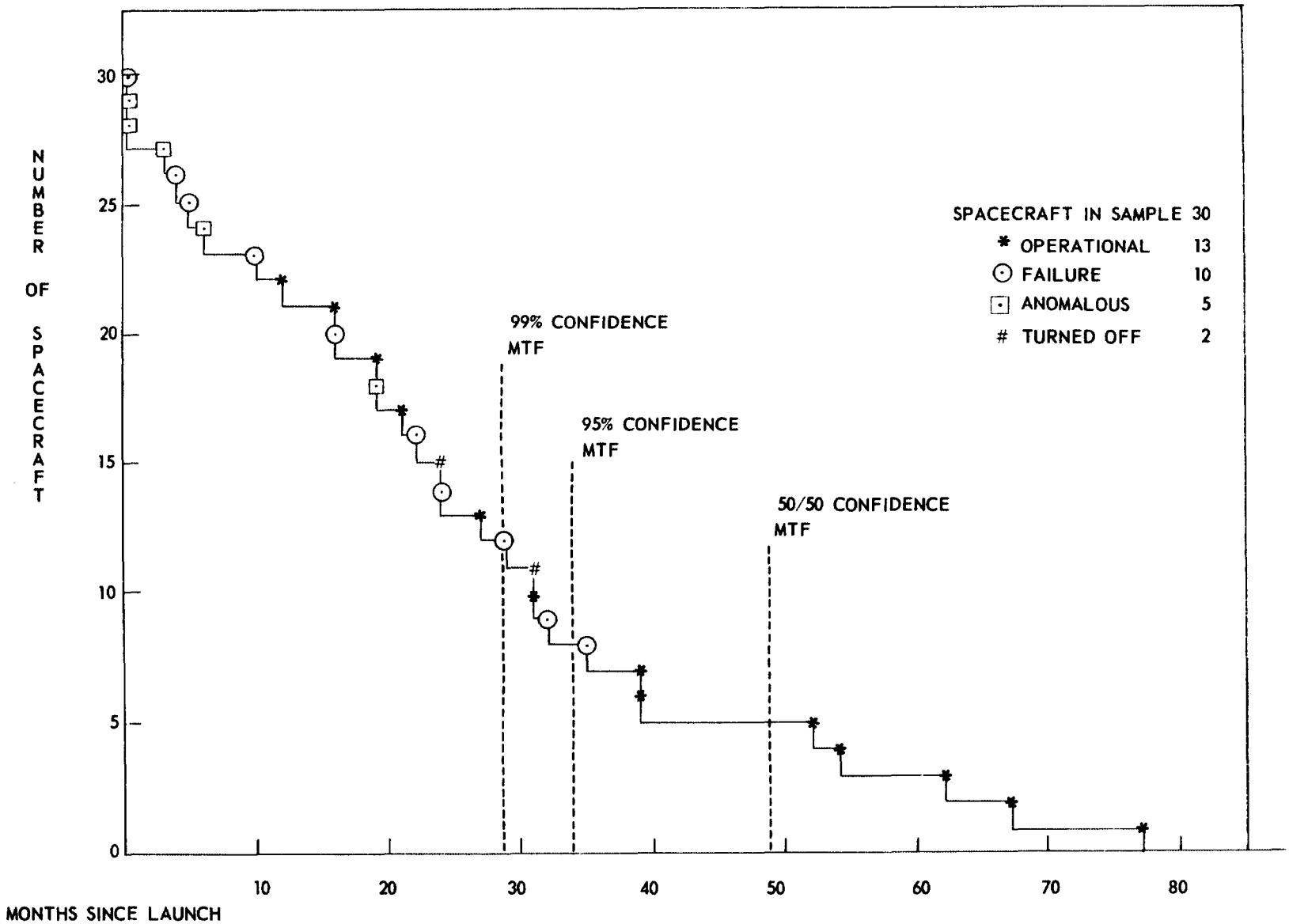
Number of Spacecraft Performing
vs.
Months Since Launch

The tendency of spacecraft failure rate to decrease after an initial period of about six months is shown on this graph. The initial or infant mortality in the first month accounts for 20% of all the failures or anomalous occurrences. An additional 26.6% of the failures or anomalous events occur prior to reaching six months in orbit.

The MTF lines represent the expected sample MTF at the indicated level of confidence.

The Performance month to Design month ratio (P/DL) for the sample is 2.1:1.0 as of March 11, 1969.

The mean performance months as of March 11, 1969 are 25.2 months.



Graph II-3. Number of Spacecraft Performing vs Months Since Launch

Graph II-4

Twelve Month Design Life

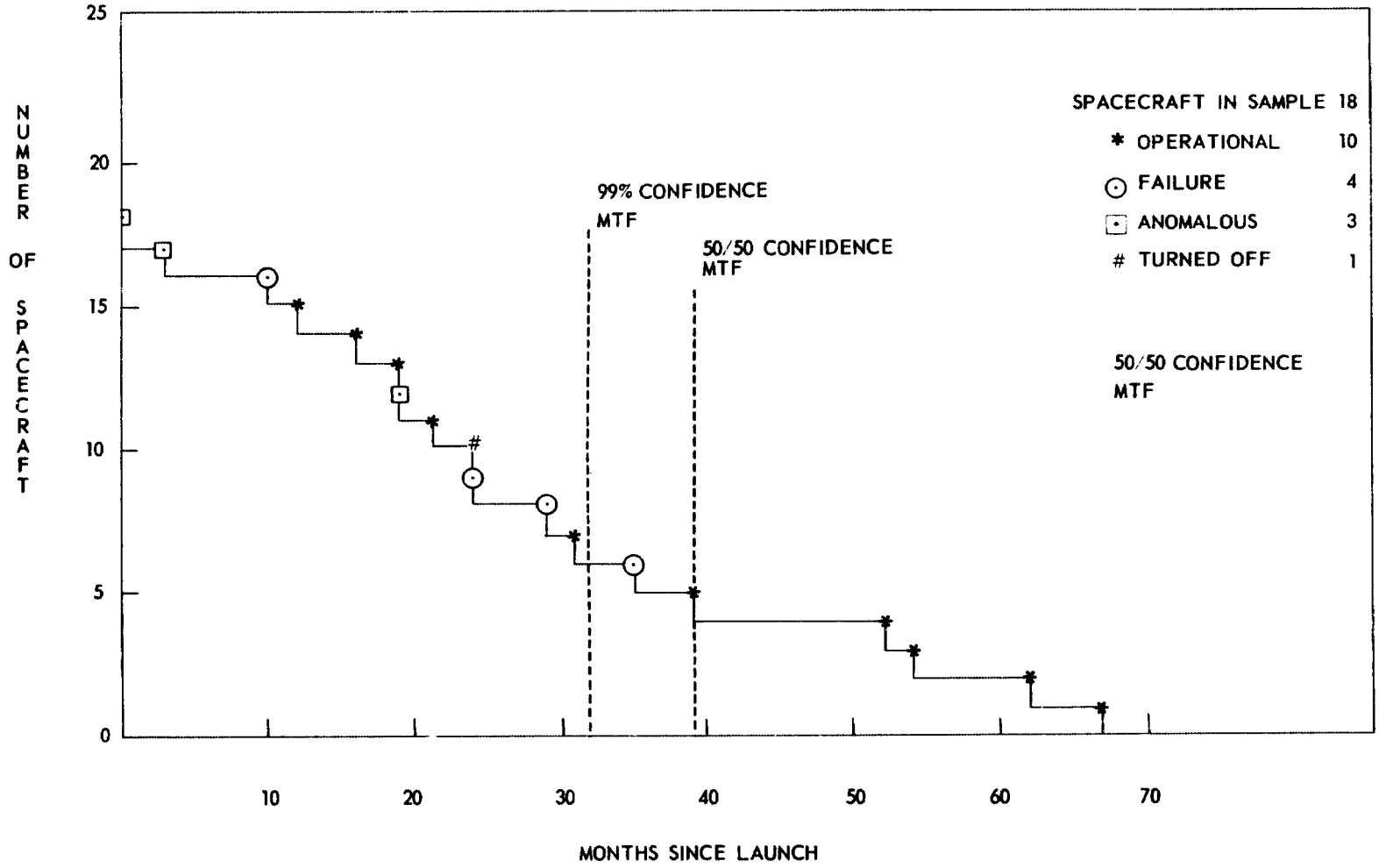
Follow-on Spacecraft Performing
vs.
Months Since Launch

The follow-on spacecraft failure rate does not exhibit the high infant mortality of the total sample. With the exception of the OGO which is considered anomalous and the Explorer XXXII (AE-B) all spacecraft have met or exceeded the design life criteria.

The MTF lines represent the expected sample MTF at the indicated level of confidence.

The Performance months to Design months ratio (P/DL) for the sample is 2.4:1.0.

The mean performance months (P/SC) as of March 11, 1969 are 28.7 months.



Graph II-4. Follow On Spacecraft Performing vs Months Since Launch

Table II-3

Mean Time to Failure Analysis

Total Performance Hours - 565,985			
Number in Sample - 30			
Number of Failures - 15			
Explorer VII Explorer XII Relay I Explorer XVIII OGO I Explorer XXVI Explorer XX Explorer XXVII		Explorer XXVIII OGO II OAO I Explorer XXXII OGO III OGO IV TTS I	
Confidence Level	MTF Hours	Months	Failure Rate % Per 1,000 Hrs.
99	21,000	29	4.7%
95	24,500	34	4.1%
90	26,200	36	3.8%
60	33,500	46	2.9%
50/50	36,000	49	2.7%

Table II-4

Follow-on
Mean Time to Failure Analysis

Total Performance Hours - 376,320			
Number in Sample - 18			
Number of Failures - 7			
Explorer XXVI Explorer XXVII Explorer XXVIII OGO II Explorer XXXII OGO III OGO IV			
Confidence Level	MTF Hours	Months	Failure Rate % Per 1,000 Hrs.
99	23,800	32	4.2%
95	28,500	39	3.5%
90	32,000	44	3.1%
60	45,000	62	2.2%
50/50	48,800	66	2.0%

APPENDIX A

RANDOM SAMPLE SELECTION PROCEDURE

Forty-six two digit numbers were selected from the first two digits of a one-hundred line fourteen column five digit random number table. Entry to a line and column was made by using two digits in the table. Columns were read down five digits, then diagonally to the next block of fives. Five entries were made to complete the sample.

Random digits were matched to launch sequence numbers to select S/C. Launch sequence numbers are chronologically assigned in "GSFC Space Program Record: August 1959 to December 31, 1967. (PEP - 067), GSFC, NASA; Greenbelt, Maryland. Twelve random digits greater than seventy-three and eight duplications were eliminated from the sample. Three launch vehicles failed. These sample numbers were replaced by the next numerical launch not already in the sample. The Telstar, launch twenty-two, was eliminated as non-Goddard Managed. Launch seventy-three carried two S/C, TTS-1 and Pioneer VIII. Pioneer VIII was eliminated as non Goddard Managed. The resulting sample is twenty-five S/C in the following programs:

Missions in sample of twenty-five

Program	Number in Sample	Mission
PIONEER	1	V
TIROS	4	I, III, IV, VII
OSO	2	I, IV, (D)
SYNCOM	2	I, II
EXPLORER	6	XVIII (IMP-A), XXVIII (IMP-C), XXXIV (IMP-F), XX (S-48)
NIMBUS	2	XXII (BE-B), XXVII (BE-C)
NIMBUS	2	I, II
OGO	2	II, IV (POGO) (D)
ESSA	1	2 (OT-2)
ESSA	3	III (TOS-A), IV (TOS-B) V (TOS-C)

Program	Number in Sample	Mission
OAO	1	I
TTS	1	I
TOTAL	25	

It should be noted that only four of the sixty-six missions successfully orbited were classifed as mission failures. Three of the four appeared in the random sample. The only unsuccessful mission not in the sample is OGO I.

The analysis of performance is based on twenty-four of the twenty-five spacecraft. The PIONEER V mission could not be included due to a lack of available data.

APPENDIX B

CHI-SQUARE CONFIDENCE INTERVAL TEST OF RELIABILITY CALCULATOR

The purpose of this appendix is to demonstrate a method which may be used in establishing approximate intervals for (1) the Mean Time to Failure (MTF) calculations and (2) to test the validity of the reliability calculator circular slide rule in developing Mean Time to Failure (MTF) calculations for the analysis.

It is assumed that an expotential model of the failure-time distribution is given by

$$f(t) = \alpha e^{-\alpha t} \qquad t > 0, \quad \alpha > 0$$

The spacecraft is the component under life test, not the related subsystems. The value of α is an assumed constant failure rate representative of the failure period which occurs following infant mortality and prior to wear out failures. The test life of the component is from launch to failure or to the end of the observation period. Spacecraft which were shut down by command were not considered to have failed.

To make inferences concerning the mean life (μ) of the spacecraft and the validity of the reliability calculator, the assumptions are an expotential model of the failure-time distribution, a fixed accumulated amount of life time (T) elapsed, and the observed number of failures (k) may be treated as the value of a random variable.

Given the above condition, an approximate confidence interval for the mean life of the spacecraft is given by

$$\frac{2T}{\chi_4^2} < \mu < \frac{2T}{\chi_3^2}$$

When T = Total observed performance hours at the end of the sample period.

μ = The mean time to failure.

Where χ_4^2 cuts off a right hand tail of area /2 under the Chi-square distribution with 2k + 2 degrees of freedom, and χ_3^2 cuts off a left hand tail of area /2 under the Chi-square distribution with 2k degrees of freedom.*

The sample examined was the twelve month design life follow-on spacecraft (Table II-4). Based on the results of the analysis (shown in Table B-1) for the conditions assumed the circular slide rule MTF estimates are considered valid.

*p. 375, Miller, I. and Freud, John E., Probability and Statistics for Engineers, Prentice Hall, Inc., Englewood Cliffs, N. J., 1965.

Table B-1

Chi-square Confidence Level Estimates of Assumed Mean Time to Failure for Twelve Month Design Follow-on Spacecraft

$$\frac{2T}{\chi_4^2} < \mu < \frac{2T}{\chi_3^2}$$

Confidence Level	2T	χ_4^2	χ_3^2	Lower Limit		μ Table II-6	Upper Limit		Failure Rate % Per 1,000 Hrs. at Lower Limit	Failure Rate % Per 1,000 Hrs. from Table II-6
				Hours	Months		Hours	Months		
99	752,640	34,267	4.075	21964	30.4	23,800	184,697	256.5	4.6%	4.2%
95	752,640	28.845	5.629	26093	36.2	28,500	133,708	185.7	3.8%	3.5%
90	752,640	26.296	6.571	28622	39.8	32,000	114,540	159.1	3.5%	3.1%
60	752,640	20.465	9.467	36777	51.1	45,000	79,501	110.4	2.7%	2.2%
50*	752,640	15.338	13.339	49070	68.2	48,800	56,424	78.4	2.0%	2.0%

T = 376,320
k = 7
n = 18
μ = MTF from Table II-6 Reliability Calculator.
α = An assumed constant failure rate occurring between infant mortality and wear out failure.
χ_4^2 = 16 degrees of freedom
χ_3^2 = 14 degrees of freedom

*The results of the 50% confidence interval test are not considered significantly in error. The calibration of the circular slide and the rounding off of numbers would account for the difference of 270 hours.